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04JUL02 E730981-1 D02651
P01/7700 0.00-0215478.9

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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road
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South Wales
NP10 8QQ

1. Your reference	562GB
2. Patent application number *(The Patent Office will fill in this part)*	0215478.9
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	Renishaw plc New Mills Wotton-under-Edge Gloucestershire, GL12 8JR
Patents ADP number *(if you know it)*	2691002
If the applicant is a corporate body, give the country/state of its incorporation	United Kingdom
4. Title of the invention	Method Of Scanning A Calibrating System
5. Name of your agent *(if you have one)*	E C Leland et al
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Renishaw plc, Patent Department New Mills Wotton-under-Edge Gloucestershire, GL12 8JR
Patents ADP number *(if you know it)*	2691003

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
–	–	–

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*
–	–

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

Yes

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	0
Description	11
Claim(s)	0
Abstract	0
Drawing(s)	4 only

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10. If you are also filing any of the following, state how many against each item.

Priority documents	0
Translations of priority documents	0
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	0
Request for preliminary examination and search *(Patents Form 9/77)*	0
Request for substantive examination *(Patents Form 10/77)*	0
Any other documents *(please specify)*	0

11. I/We request the grant of a patent on the basis of this application.

Signature AGENT FOR THE APPLICANT Date 04.07.2002

12. Name and daytime telephone number of person to contact in the United Kingdom A Iles 01453 524524

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c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

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Method of calibrating a scanning system.

The present invention relates to a method of calibrating a scanning system. A scanning system in this specification should be understood to mean a combination of a machine and a probe which together are capable of use in scanning an object in order to obtain information about its size, shape or surface contours.

The machine may be, for example, a co-ordinate measuring machine (CMM) or robot, and the probe is an analogue probe with a workpiece-contacting stylus. The machine has measuring devices for measuring the movement of the machine parts in three nominally orthogonal directions (referred to as X,Y and Z axes), and the probe includes measuring transducers for producing outputs indicative of the displacement of the tip of the stylus relative to the probe in three nominally orthogonal directions (referred to as the a,b, and c axes). Although the term 'analogue probe' is used, the outputs for the a,b and c axes may be either analogue or digital.

In known systems, measurement errors are caused by deflections of the probe and machine structure. Errors due to bending of the probe stylus are the same throughout the machine volume and may be compensated for by probe calibration. Errors due to deflections in the machine structure may be caused, for example, by the machine quill bending and the machine bridge twisting and vary throughout the machine volume. These errors increase, for example, with increasing cantilevers.

Parts of the working volume of the machine may be calibrated for measurement errors by using a calibration artefact such as a calibration sphere. However usually the calibration artefact cannot be located at the same position in the machine's working volume as the part to be measured and is instead located to one side. The measurement errors determined at the calibration artefact will thus be different to those on the part.

Methods of correcting machines for acceleration induced errors are known. One example of such a method is described in European Patent No. 318557. In this method a first article from a batch of nominally identical articles is scanned at a relatively slow speed, noting the measurements of the positions of a number of datum points on the article. The scanning operation is repeated at a relatively fast speed noting the measurements of the positions of the same points. Any difference in the measurements are noted as errors in a correction table.

Thereafter all of the articles are scanned at the relatively fast speed taking measurements of the positions of corresponding points on each article, and these measurements are corrected for machine accelerations using the previously noted errors.

Another method of correcting errors is disclosed in WO 00/62015. In this method a stylus of a probe mounted on a coordinate measuring machine is driven into contact with a surface of an object in a direction normal to its surface until a predetermined stylus deflection has been reached. The machine is then

reversed whilst simultaneously recording the outputs of the machine measuring devices and measuring transducers of the probe. This process is repeated for a selection of datum points around the surface of the object. This information is used to determine the positions for each of the points when the probe is just in contact with the surface, ie when the probe deflection is zero, having just left the surface.

The object is then scanned several times at a slow speed and predetermined stylus deflection. The difference at the datum points between the initial measurements and the scan is recorded.

The scans are repeated at the same stylus deflection at greater speeds until the variation in the recorded differences between the fast scan and the initial measurements and the slow scan and the initial measurements exceeds a defined tolerance. The last speed which falls within this tolerance is the maximum scanning speed. A map of the positional errors at the datum points is stored along with the data relating to the scanning speed, particular artefact, particular CMM and probe and stylus configuration etc. It is possible to interpolate from this map to obtain radial errors at angles in between the radial directions at which actual data was obtained (ie the datum points).

This method has the disadvantage that the step of interpolating between the datum points is time consuming.

The present invention provides a method of measuring an

object on a coordinate positioning apparatus, comprising the steps of:

placing a first object on a coordinate positioning apparatus;

measuring said first object with a workpiece contacting probe, the probe having a first stylus deflection or first constant force;

measuring said first object one or more subsequent times, each with the probe at a different stylus deflection or different constant force;

for a plurality of points on the surface of said first object, extrapolating the measurement data to that corresponding to zero stylus deflection or zero probe force;

creating an error map;

measuring subsequent objects at a given stylus deflection or constant force;

and using the error map to apply an error correction to the measurements of the subsequent objects.

Preferably the steps of the measuring the first object with a workpiece contacting probe comprise scanning the first object.

The object may be a part in a series of substantially identical parts or an artefact with features approximating those of a series of parts to be measured.

Preferably the first and subsequent objects are measured at a slow speed. The error map is thus a measure of probing force errors.

Preferably a second step of the invention comprises:

measuring the first object at a fast speed;

comparing the measurements taken at the fast speed with the corrected measurements relating to zero stylus deflection or zero probe force;

creating a second error map;

measuring subsequent objects at a given stylus deflection or constant force at the fast speed;

and applying an error correction using the second error map to the measurements of the subsequent objects.

This second error map relates to dynamic errors caused by the probe moving at fast speed. The dynamic errors may result for example due to quill bending caused by acceleration.

The first and second error maps may be combined to form a single error map. This map thus corrects for both probing force errors and dynamic errors together.

A second aspect of the present invention provides a method of measuring an object on a coordinate positioning apparatus, comprising the steps of:

placing a first object on a coordinate positioning apparatus;

measuring said first object with a workpiece contacting probe, the probe having a first force;

measuring said first object one or more subsequent times, each with the probe having a different force;

for a plurality of points on the surface of said first object, extrapolating the measurement data to that corresponding to zero probe force;

creating an error map;

measuring subsequent objects at a probe force; and using the error map to apply an error correction to the measurements of the subsequent objects.

Preferred embodiments of the invention will now be described with reference to the accompanying drawings in which:

Fig 1 is a schematic diagram of an analogue probe mounted on a coordinate measuring machine;

Fig 2 is a schematic representation of several different constant stylus deflection scans around an object;

Fig 3 is a graph illustrating probe deflection against object diameter;

Fig 4 is a schematic representation of several different constant force scans around an object;

Fig 5 is a schematic illustration of the static correction vectors;

Fig 6 is a schematic illustration of the dynamic correction vectors; and

Fig 7 is a schematic diagram of a second embodiment of the invention.

In a first step of the invention, a measurement error map is generated for an object. This is achieved by mounting an analogue probe 10 on the quill 12 of a coordinate measuring machine (CMM) as shown in fig 1. The analogue probe 10 has a deflectable stylus 14 with a workpiece contacting tip 16. The object 18 to be measured is mounted on the CMM machine table 20 and the probe 10 is driven slowly by the machine quill 12 in a path around the object. The object 18 is first scanned along a path at a first constant probe deflection, for

example 300μm. The object is then scanned along this path at one or more different subsequent probe deflections. For example, the part may be scanned a second time with a probe deflection of 200μm and a third time with a probe deflection of 100μm. Fig 2 shows a representation of the object 18 and the first 22, second 24 and third 26 scans around it. Each point on the object 18 will thus have three different measurements A,B,C, resulting from the three different scans at different probe deflections. For each point on the object, the measurements may be extrapolated back to zero to calculate the measurement if the probe deflection is zero. Fig 3 shows a graph of the probe deflection against object diameter. The actual object diameter is shown at zero probe deflection. The step of extrapolating to zero probe deflection allows the measurements at zero probe deflection to be determined without the errors of actual measurement, caused by probing errors. A passive probe is suitable for use in this method, such a probe may comprise a stylus deflectable against springs.

This information enables a measurement force error map of the part to be produced. As the scans of the part were taken at a slow speed, this results in negligible dynamic errors due to very low accelerations of the probe and machine.

The measurement force error map may be in the form of a look-up table, with different error corrections for different stylus deflections. Alternatively, the error map may be in the form of a polynomial function.

Fig 5 shows the error corrections for points on the

scan. Each point on the scan has a radial correction 38which is applied for a certain stylus deflection. If a subsequent object is scanned at a stylus deflection of 300µm 36, the static error map may be used to correct the data to correspond to the part being scanned at a deflection of 0µm 34.

Alternatively, instead of scanning the object several times at different probe deflections, it may be scanned several times with the probe having a different constant force for each scan. For example, the object may be first scanned with a constant force between the stylus and the object of 0.3N. The object may then be scanned a second time with a constant force of 0.2N and a third time with a constant force of 0.1N. Each of these scans may have the same or different stylus deflections. Fig 4 shows a representation of the object 18 and the first 28, second 30 and third 32 scans at different constant probe forces.

As before, for a point on the surface of the object, there are three sets of data relating to the scans at different probe forces. This data may be extrapolated back to zero force to enable the point which would be measured with zero force between the stylus and workpiece to be determined. As described previously, an error map may be created relating the 'correct' measurements for a given point determined for zero probe force by the extrapolating to zero technique. Subsequent measurements at a given probe force may be corrected for measurement errors using this measurement error map.

The object may comprise a part of a series of parts to

be measured. In this case a measurement error map of this part is produced by this method. Alternatively, the object may comprise an artefact having features corresponding to the features on the parts to be subsequently measured. These features may be, for example, spheres, ring gauges, plug gauges etc. Use of the artefact allows geometric errors in addition to the measurement errors, to be determined. As the forms of these features are known, they may be used to correct for geometric errors of the machine and probe. This may be done by comparing the scanned map of the artefact with the known form of the feature and producing a geometric error map to correct subsequent parts with.

Alternatively the geometric error of the machine and probe may be determined in a separate step. Geometric errors are errors of the machine and probe, for example non-linearity of the machine scales or the machine axes not being straight. The step of combining geometric and measurement error determination has the advantage that it is not necessary to have a second accurate machine on which to accurately measure parts for comparison.

In a second step of the invention, the dynamic errors are determined. Dynamic errors may be caused, for example, by machine bending due to acceleration. Once the measurement error map has been produced, the object is scanned at a high speed. The high speed scan is at either constant probe deflection or constant force, as above. In addition, the high speed scan is preferably performed at a constant speed. The measurement data from this fast scan is compared with the measurement

error corrected slow scan relating to the actual dimensions of the object, produced as described in the first step of the invention. A dynamic error map may be produced by comparing the fast scan and the measurement error corrected slow scan. This dynamic error map is used to correct subsequent scans taken at a fast speed.

Fig 6 illustrates the measurements of the fast scan 40 and the actual dimension 42 of the object created by measurement error correcting the slow scan as previously described.

The two separate error maps produced by this method (ie the measurement and dynamic error maps) may be combined to create a total feature map. This is done by adding the probing force error correction vectors 38 around the part illustrated in fig 5 with the dynamic error correction vectors 44 around the part illustrated in fig 6.

This method has the advantage that as the measurement errors are determined by scanning the object at different probe deflections or different constant forces, the measurement errors are known for every point on the surface of the object. Thus no interpolation is required.

A second embodiment of the invention will now be described with reference to fig 7. A stylus of a probe is driven into contact with a surface of an object 18 along a path 46 in a direction normal to the object's surface until a predetermined stylus force has been reached. This step is repeated along the same path for

a plurality of different predetermined stylus forces. The measurement data along this path is used to extrapolate back to zero force to enable the point which would be measured with zero forces between the stylus and workpiece to be determined. This is the nominal object measurement.

This process is repeated for a selection of datum points around the surface of the object. The data from each of these datum points is used to create an error map as previously described to correct subsequent measurements. Measurements of the surface of the object between the datum points are corrected by interpolating the error map between the datum points.

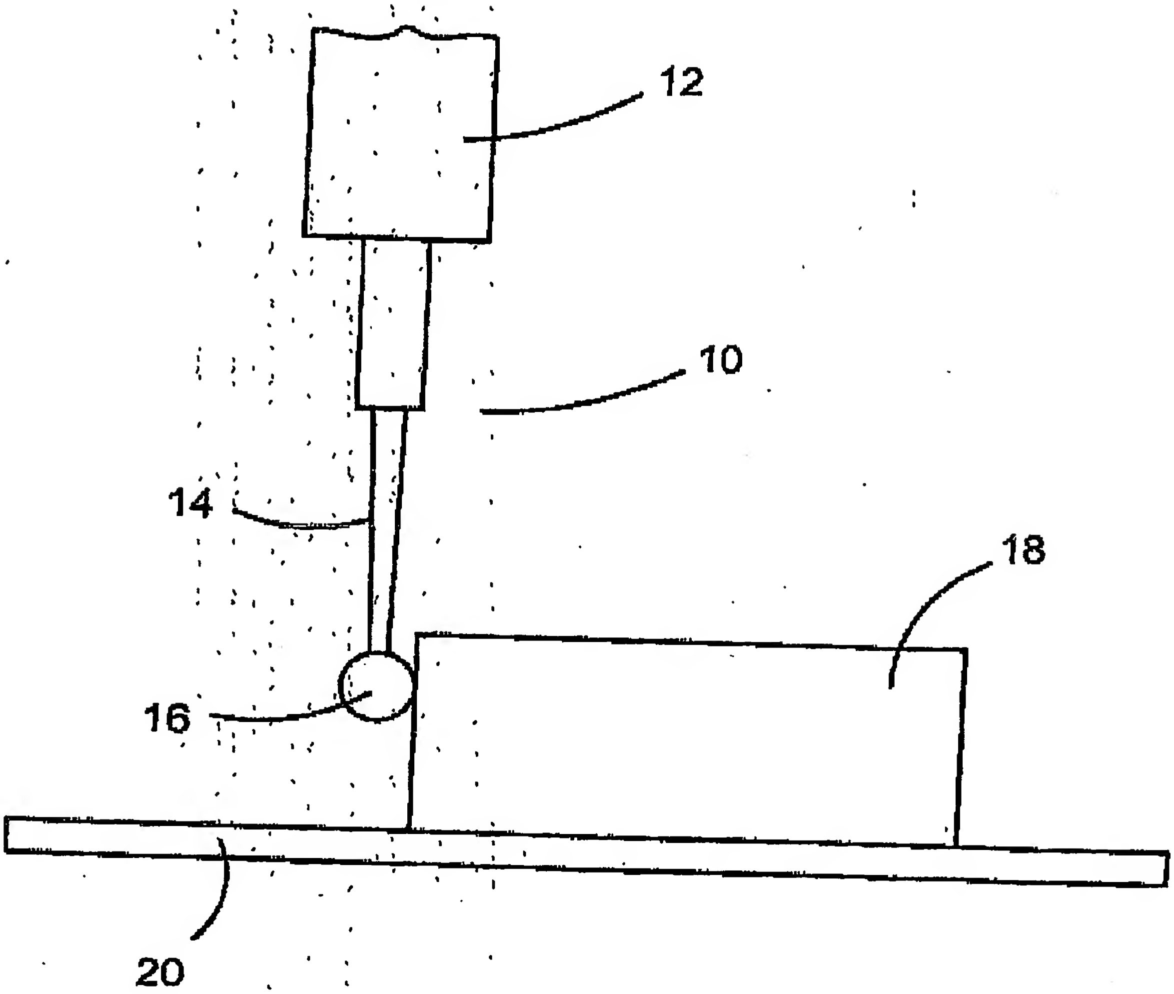

Fig 1

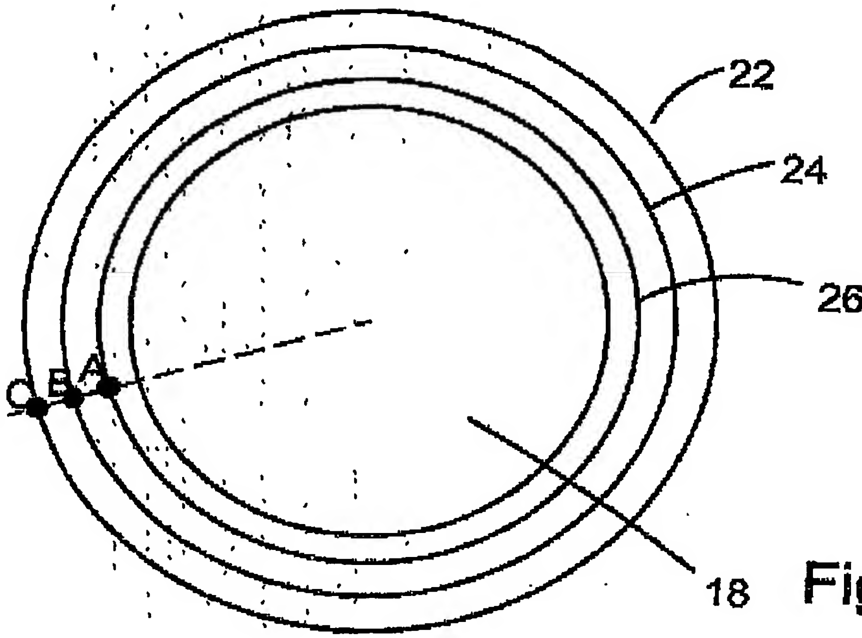
22
24
26
A
B
C
18

Fig 2

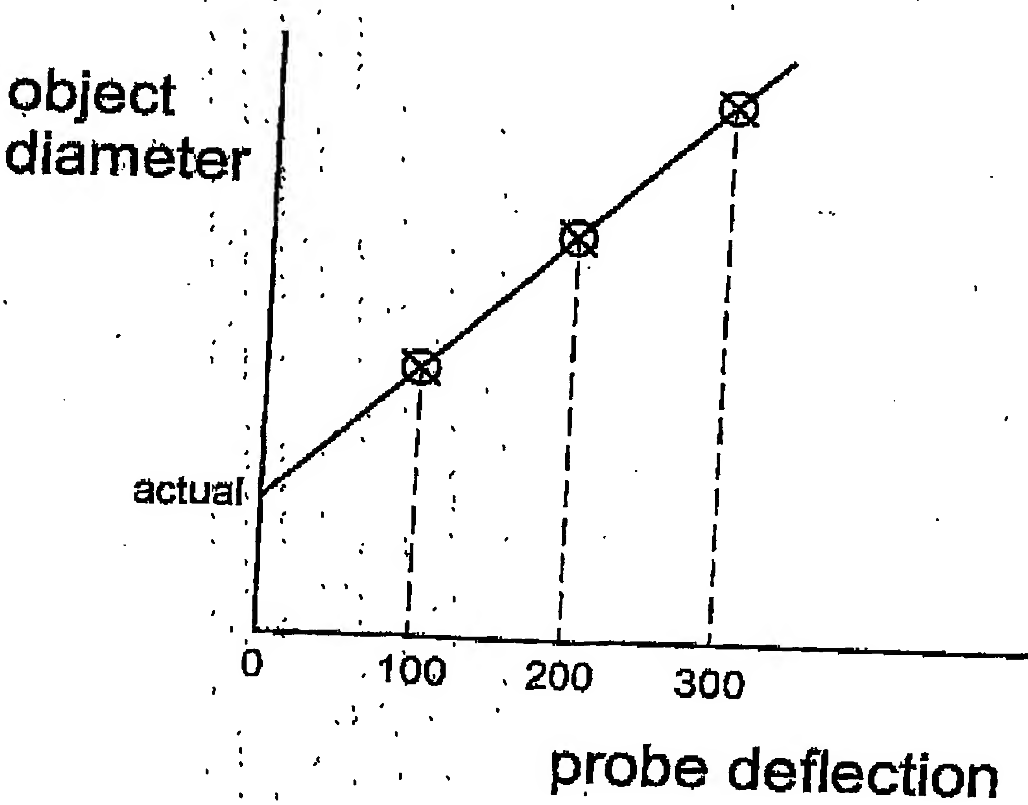
object diameter
actual
0
100
200
300
probe deflection

Fig 2

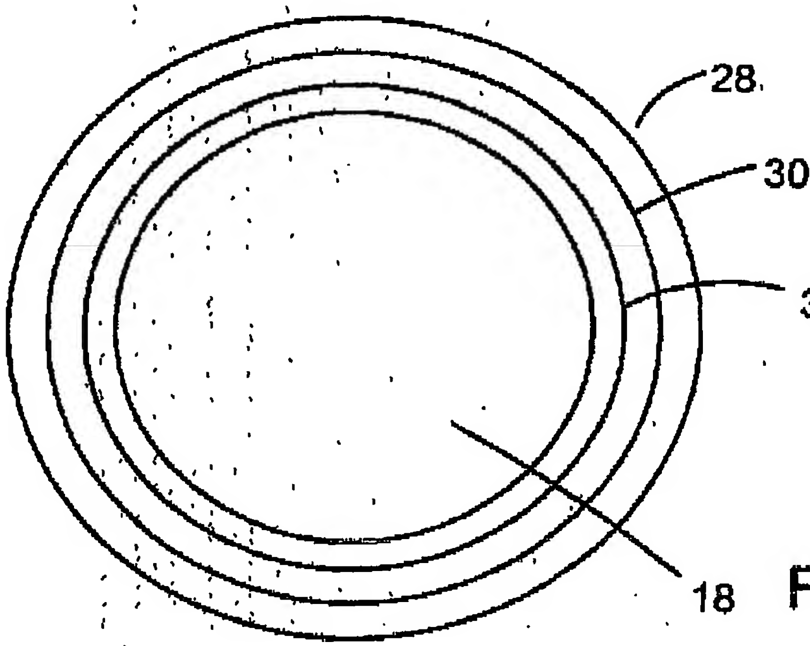

Fig 4

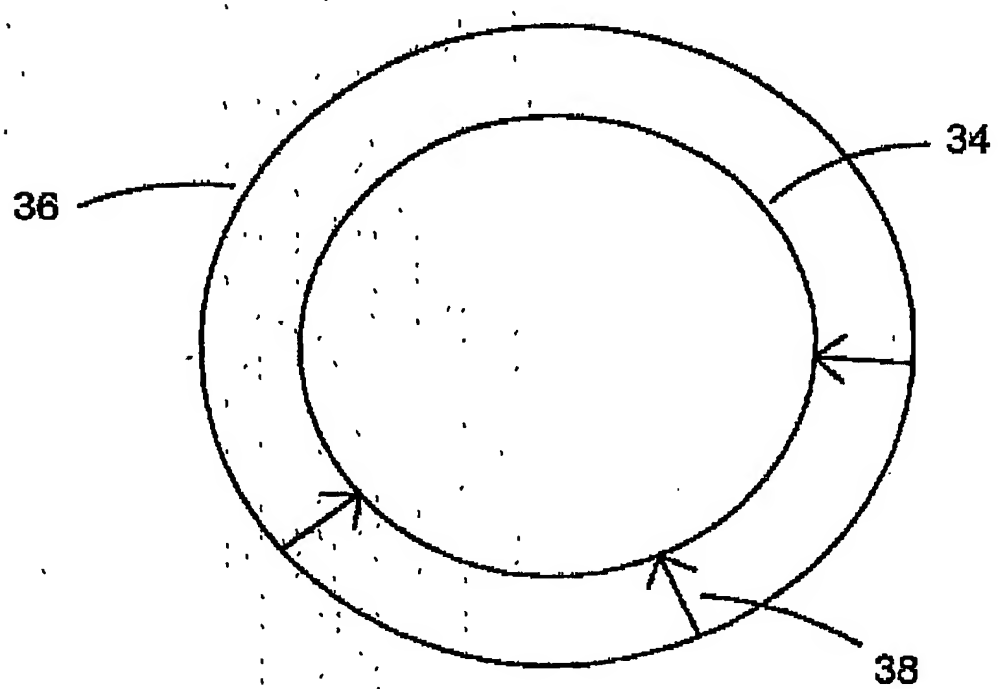

Fig 5

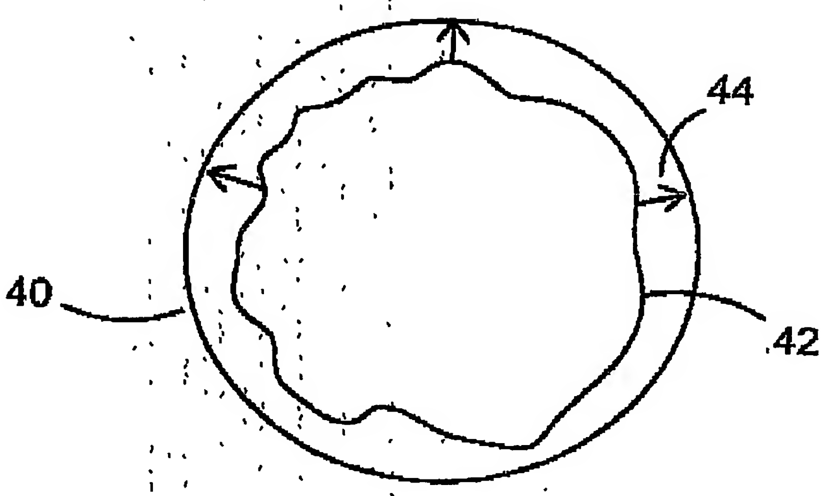

Fig 6

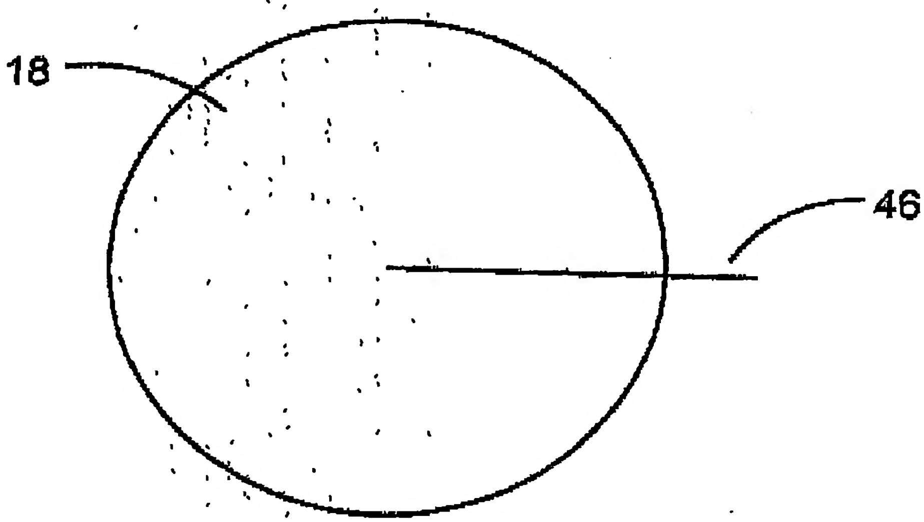

Fig 7